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Novelty, Stimulus Control, and Operant Variability

Timothy A. Shahan
University of New Hampshire

Philip N. Chase
West Virginia University

Although behavior analysis has been criticized for failure to account for response novelty, many common behavior-analytic concepts and processes (e.g., selectionism, the operant, reinforcement, and stimulus control) assume variability both in the environment and in behavior. The importance of the relation between variability and novelty, particularly for verbal behavior, is discussed, and concepts used to account for novel behavior are examined. Experimental findings also are reviewed that suggest that variability in behavior can come under discriminative control, and these findings are applied to describe novel instances of behavior that may arise during problem solving. We conclude that variations provided and selected by the terms of the three-term contingency are powerful means for understanding novel behavior.

Key words: novelty, stimulus control, variability, the operant, verbal behavior, problem solving, creativity

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Psychology, as described from a behavioral perspective, has been criticized for its failure to account for novelty in behavior. For example, in a famous critique of Skinner (1957), Chomsky (1959) asked how people can read and understand a newspaper when they undoubtedly come upon countless sentences that are dissimilar in a physical sense from any that they have seen before. Chomsky's question summarized a general problem that many have had with understanding environmental influences on complex behavior. His conclusion was that the concepts of behavior analysis may provide objective variables for the study of simple behaviors in controlled experiments, but that they are fruitless for understanding the kind of novelty that occurs in many examples of human behavior. Although MacCorquodale (1970) convincingly argued that Chomsky had confused Skinner's analysis with other behavioral theories, some of Chomsky's claims about novelty have still not been refuted.

Behavior analysis begins an account of novel behavior with the concept of the operant (Skinner, 1937; see also Catania, 1973) and the generic definitions of stimulus and response contained therein (Skinner, 1935). The operant is a class of responses affected similarly by a characteristic consequence. By describing how a set of topographically different behaviors can be selected by a given consequential relation, Skinner explicitly expanded the role of environmental influences on behavior beyond the elicitation of a fixed response, and explicitly included variation in responding in the subject matter of behavior analysis. The variability in responding that may be included in an operant is extended further in concepts such as imitation and rule governance, which have been described as higher order response classes (Catania, 1998). The term *higher order* refers to the vast topographic variability in responses that are classified together because of a common consequence. In addition, given that op-

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Address correspondence to Timothy A. Shahan, Department of Psychology, Conant Hall, University of New Hampshire, Durham, New Hampshire 03824 (e-mail: tshahan@cisunix.unh.edu) or Philip N. Chase, Department of Psychology, P.O. Box 6040, West Virginia University, Morgantown, West Virginia 26506-6040 (e-mail: pchase@wvu.edu).

erant behavior is always under stimulus control (at least implicitly), the discriminated operant, or the three-term contingency of antecedent–behavior–consequence, was defined by Skinner as the fundamental unit of operant behavior. Because the discriminated operant is based on relations between *classes* of stimuli and *classes* of responses, variability is an inherent characteristic of this fundamental unit.

The variability in behavior defined by the operant has formed the basis for many behavior-analytic accounts of novel behavior (see Balsam, Deich, Ohyama, & Stokes, 1998, for a recent review). Other behavior-analytic accounts have emphasized the concepts of stimulus control, such as generalization, conceptual behavior, tact extension, abstraction, minimal repertoires, the autoclitic, and equivalence (see G. Alessi, 1987, for review). What might be needed, though, is a place where these behavior-analytic concepts are integrated. This would provide a convenient reference for students of behavior analysis, as well as critics who are interested in thoroughly reviewing modern behavior-analytic accounts. In what follows, we will first explore issues related to defining novelty. Next, we will examine concepts related to stimulus control and describe recent advances in the experimental analysis of variability in operant behavior. We will end with a brief discussion of how variations in consequences contribute to novel behavior. Throughout, we will examine the importance of these concepts for understanding novel instances of verbal behavior.

DEFINING NOVELTY

A conceptual precursor to dealing with novelty from any perspective is determining what behavior should be considered novel. In some sense, all behavior could be considered novel because behavior varies in topography from instance to instance and occurs under conditions that are in part unlike any set of stimulus conditions previously encountered by an organism. Even if a set of stimulus conditions is reencountered, the organism's history will differ from one presentation to the next, and the instances necessarily occur at different times. As stated in popular lore, one never steps in the same river twice. At this extreme, the entire analysis of behavior is the study of novel behavior (cf. Epstein, 1996). The use of the word *novel,* however, is worthless if every instance of behavior is novel, because in describing everything, novelty characterizes nothing.

An alternative approach is to consider no behavior as novel. For example, if one carefully examines the history of an organism, nearly every behavior is found to be an instance of a class of behavior that occurred previously. Every behavior can be said to fall into a few large higher order classes (e.g., food getting, reproduction, imitation, rule-governed behavior) with varied but possibly irrelevant topographies (cf. Epstein, 1996). In contrast to the above lore, there is nothing new under the sun.

Neither of these extremes is very satisfying pragmatically. The appropriate pragmatic level of analysis in any situation is that level which allows effective prediction and control of behavior. For example, even if all behavior is considered novel at some general level of analysis, one adopts standards of judgment to distinguish novelty at more specific levels of analysis. Evaluations of originality, creativity, and plagiarism suggest examples of the importance of such judgments. Similarly, even if all behavior is considered part of a few repeatable classes in which the topographies vary extensively, prediction and control may be enhanced by further classifying the behavior. For example, the first instance of food getting involving the use of a tool might be considered important to distinguish from other topographically different types of food getting.

Based on a level of analysis that is effective for a given situation, novel behavior involves instances when the context, response topography, or consequences vary, and the variation observed is considered important. The exact conditions giving rise to a description of behavior as novel will depend on both the behavior of the organism being observed and the observer's level of analysis and knowledge of the organism's history (Chase & Bjarnadottir, 1992). Such a general definition of novelty easily subsumes more precise definitions used in particular literatures. For example, Goetz and Baer (1973) defined novel forms contained in children's block constructions as forms "that had not appeared in any prior construction by that child (in previous sessions of blockbuilding) recorded within the study" (p. 210).

STIMULUS CONTROL ACCOUNTS OF NOVELTY

We start with the behavioral concepts of stimulus control, which will be defined and applied to types of novel behavior they help to describe. Some of these concepts are well known and others are less well known, but the ways in which complex combinations of these concepts help to account for novelty may be seen best if each is defined and illustrated.

Stimulus Discrimination

The basic unit of stimulus control is discrimination. When behavior is brought under control of a stimulus through differential reinforcement, the relation between the stimulus, the behavior, and the consequence is called discriminative control. The stimulus is described as a discriminative stimulus, and the process is sometimes called discrimination. Many examples of discrimination have been observed and recorded. Early research showed that the presentation of a colored light prior to a key peck that was followed by food, and the absence of that colored light when the key peck was not followed by food, resulted in the reliable occurrence of the key peck in the presence of the light and not in the absence of the light. Later it was found that this basic contingency could be observed with stimuli, responses, and consequences that varied in complexity. The stimuli could be shapes, images, cartoon characters, photographs, ongoing behavior, or the verbalizations of other individuals. The response could be pressing, pointing, touching, or sorting that selected a stimulus, or the responses could have unique topographies, like saying a name in the presence of the stimulus. Discrimination, even in its simplest arrangement, provides the grist for novel responding to occur under the conditions of stimulus generalization.

Stimulus Generalization

Stimulus generalization refers to the finding that behavior under discriminative control also occurs, without training, in the presence of stimuli similar to the original stimulus (e.g., Guttman & Kalish, 1956). The novel stimuli differ from the original stimulus along some dimension (e.g., wavelength) or dimensions. Although the novel stimuli may occasion responses previously reinforced in the presence of another stimulus, responses to the novel stimuli usually occur at a lower rate, with a longer latency, or with a lower intensity than responses occasioned by the original stimulus. This behavioral variability is critical to our description of the conditions that give rise to novelty, but we will return to this later under the section on behavioral variability. Our point here is to illustrate one form of control by novel stimuli. Stimulus generalization provides a basis for understanding responses that occur in the presence of novel stimuli that are similar to a previously established discriminative stimulus.

Conceptual Behavior

Conceptual behavior refers to responding similarly to stimuli that are members of a class and responding differently to stimuli that are not members of that class (Keller & Schoenfeld, 1950; Wasserman & Bhatt, 1992). Membership in a stimulus class may be based on the similarity of stimuli; however, it is not necessary for the similarity to be along any easily specifiable dimension or combination of dimensions. For example, we may respond "chair" in the presence of stimuli that vary considerably along many dimensions without specifying the defining dimensions of the class. Although the response "chair" is an example of conceptual behavior in the verbal behavior of humans (see also Tact Extension below), nonhumans may also behave conceptually.

For example, Herrnstein, Loveland, and Cable (1976) trained pigeons to respond differentially to slides containing the presence versus the absence of trees, bodies of water, or a particular person. Responding was differentially reinforced in the presence of slides containing an instance of the specified object. As many as 1,840 different photographs that varied widely were used for a particular type of object. Discriminated responding in the presence of hundreds of novel slides (including sessions in which only novel slides were presented) was obtained after training with no more than about 700 slides. Similar discriminated responding in the presence of complex novel stimuli has been demonstrated many times with pigeons (e.g., Bhatt, Wasserman, Reynolds, & Knauss, 1988; Cook, Katz, & Cavoto, 1997; Herrnstein, 1979; Herrnstein & Loveland, 1964; Lubow, 1974; Wasserman, Kiedinger, & Bhatt, 1988; Watanbe, Sakamoto, & Wakita, 1995; see Herrnstein, 1990, for a review). It appears that the behavior of pigeons in these conceptual behavior experiments is under the control of "clusters of features more or less isomorphic with the clusters we respond to ourselves" (Herrnstein et al., 1976, p. 298; see also Wasserman & Bhatt, 1992), even though the relevant features are not precisely known (but see Huber, Troje, Loidolt, Aust, & Grass, 2000). Although specifying the dimensions of the stimulus class may allow us to select a range of examples of the class and examples of contrasting classes more exactly (cf. Engelmann & Carnine, 1982), often we do not need to do so. Even without specifying the dimensions that define the class, reinforcing responses in the presence of stimuli in the class and withholding reinforcement for responses in the presence of stimuli outside the class may be sufficient to produce appropriate responding in the presence of novel members of the class.

Tact Extension

Discriminative control involving complex stimulus classes permits an enormous amount of behavioral flexibility in novel situations. As in the examples with pigeons above, appropriate responding occurred to stimuli with the relevant properties in a novel context. Skinner (1957) discussed such extensions of responding to novel situations in verbal behavior as *tact extension.*

Tact extension refers to verbal responses to stimulus properties that have previously acquired a discriminative function but now appear in a novel context (Skinner, 1957). Generic tact extension occurs when a response under the control of some object, event, or some property of an object or event (i.e., a tact) occurs in a novel context that includes a set of defining features. The defining features are those aspects of the stimuli that are required for a tact of a specific form to be reinforced by the speaker's verbal community. For example, a child's tact "hurdy-gurdy" is reinforced only in the presence of a particular box with a crank that produces music. In generic extension, the response "hurdy-gurdy" occurs in the presence of a hurdy-gurdy in the context of new variable features (e.g., a hurdy-gurdy is seen on the street for the first time). Metaphoric tact extension describes cases in which the tact occurs in the presence of some of the defining features of the object or event, even though others of these features are absent or are configured differently than when the response was previously reinforced. For example, a child may respond "hurdy-gurdy" to a player piano or an accordion. A response to features that often accompany the defining features of some stimulus, but do not include the defining features, is an instance of metonymical extension. A child's response "hurdy-gurdy" in the presence of a small monkey in a bellhop's uniform would be an example of metonymical extension.

As a form of conceptual behavior, tact extension describes many instances of behavior that would generally be considered novel. Responses can occur in situations not encountered previously by the organism because of complete or partial control by a set of environmental features. Conceptual behavior and, therefore, tact extension differ from generalization. In the former, the response is occasioned by stimulus properties that were present when the behavior was previously reinforced, but they now appear in a novel context (i.e., with other irrelevant properties). In the latter, the response occurs in the presence of a novel variation of a relevant stimulus property. In addition, conceptual behavior, tact extension, and stimulus generalization can be combined, as in instances in which one or more of the defining features vary across some measurable dimension and occurs in a novel context with additional stimulation. Conceptual behavior, tact extension, and stimulus generalization are based on behavior that has previously been brought under discriminative control.

One problem with relying on generalization, conceptual behavior, and tact extension to account for novel behavior is that confusion would quickly ensue. Skinner's extensive analysis of tact extension makes this clear; almost any feature of the environment that accompanies the stimulus present when a response is reinforced could control the response in the future. For example, following reinforcement for saying "hurdy-gurdy" in the presence of a picture of a music box with a crank, a man with a curly mustache, and a monkey in a bellhop's uniform, a child might say "hurdy-gurdy" in the presence of other boxes that make music, monkeys, bellhops, men with curly mustaches, and so forth. If unchecked, such extension would lead to greater and greater diffusion of control. The child might then say "hurdy-gurdy" in the presence of the stimuli accompanying these new situations, for example, the attendant at a zoo where he or she saw monkeys. This diffusion of control would occur to the extent that one would never be able to predict the occurrence of "hurdy-gurdy," and our understanding would be limited. Such overextension does occur, and accounts for some novel behavior, but this novelty generally is maintained only by specialized audiences. Parents and siblings may maintain overextension in young children (e.g., cute phrases or twin talk). Literary audiences may maintain overextension within artistic endeavors. The probability of detrimental overextension, however, is limited by another process, described by Skinner (1957) as *abstraction.*

Abstraction

Abstraction is related to tact extension. Abstraction helps to describe how the process of tact extension is kept under sufficient control to maintain its utility. Abstraction occurs when discriminative control by a relevant stimulus property or properties is refined by the differential reinforcement of responses to stimulus properties respected by the verbal community. The term *abstract* is a description of behavior under the precise discriminative control of relevant defining stimulus properties. Often the control is by a single property, like color. Sometimes control is defined by multiple properties, like some shapes. Still other examples involve complex concepts or tacts, like identifying the principle of reinforcement within classroom situations. Furthermore, Skinner (1957) suggested that "a well-established common tact is necessarily an abstraction: it is under the control of a subset of properties which may be present upon a given occasion but probably never exclusively compose such an occasion" (p. 113). Skinner also suggested that abstraction may be a purely verbal process because only a verbal community provides the stringent sort of contingencies and generalized conditioned reinforcement required for the refined stimulus control that defines abstraction.

Together the concepts of discrimination, generalization, extension, and abstraction account for a wide range of control by complex stimuli. From the example given earlier, saying "hurdy-gurdy" is differentially reinforced in the presence of a box with a crank that produces music, and the presence of these stimuli continues to occasion saying "hurdy-gurdy" (discrimination). Saying "hurdy-gurdy" also occurs when a new bigger box is introduced (generalization), when the original stimuli occur in a novel context (generic extension), when nondefining features of the original context occur without the original stimuli (metonymic extension), and when some of the original stimuli occur without all of them (metaphoric extension). Some instances of generalization and extension occur and are reinforced, but others are not reinforced. This differential reinforcement produces the refined control known as abstraction. This evolution of control is sometimes discussed as a dual process of discrimination: Such complex stimulus control involves discrimination of relevant from irrelevant stimuli as well as discrimination of the relevant properties of one abstraction from other abstractions (Becker, Engelmann, & Thomas, 1975).

Minimal Repertoires

The processes of discrimination, generalization, abstraction, and extension produce another concept critical to novel stimulation, identified by Skinner (1957) as minimal repertoires. Novel situations are often identified by the novel combination of environmental properties that gain control of verbal behavior. The properties that control the abstract and common tact "tree" may occur in combination with the properties that control the abstract and common tact "tall" to form the first instance of "tall tree." Skinner described each of the component repertoires as *minimal repertoires* and provided many examples. Minimal repertoires may be in the form of phonemes, morphemes, words, phrases, sentences, or other units of behavior that are repeated and come under abstract control. Once established, such minimal repertoires may be combined to form novel tacts given novel combinations of properties.

Very little research has been dedicated specifically to the combination of minimal tact repertoires; however, related research on miniature linguistic systems (e.g., Wetherby, 1978; Wetherby & Striefel, 1978), contingency adduction (Andronis, Layng, & Goldiamond, 1997), transfer of functional stimulus control (Ellenwood & Chase, 1995), the independence of tact and mand repertoires (Hall & Sundberg, 1987; Lamarre & Holland, 1985), the independence of various forms of instructional intraverbals (Chase, Johnson, & Sulzer-Azaroff, 1985), and joint control (Lowenkron, 1998) may be interpreted in terms of minimal repertoires. For example, Wetherby and Striefel reviewed studies of miniature linguistic systems that have produced instruction following with novel verb–noun combinations (e.g., "push block"), and use of novel plural and past tense forms of nouns and verbs (e.g., "car" and "cars" and "playing" and "played"). What is common to these studies is the use of a matrix to analyze the components for all possible combinations (i.e., minimal repertoires). Discriminative functions are then established for each minimal component by training with selected combinations from the matrix. For example, in a simple 3 × 3 matrix of three verbs (e.g., *push, drop,* and *touch*) and three nouns (e.g., *ball, glass,* and *car*), subjects could be taught to follow the instructions "push ball" and "push glass," "drop glass" and "drop car," and "touch car." Then, when faced with a novel combination of the first verb and the third noun, "push car," the second verb and first noun, "drop ball," the third verb and the first noun, "touch ball," or the third verb and second noun, "touch glass," the subject would follow the instruction correctly. Thus, by explicitly establishing each minimal repertoire, the subjects responded to novel instructions that combined the minimal units.

The Autoclitic

To understand the conditions that produce a first instance of combining two minimal repertoires (e.g., "tall tree"), however, requires a least one more behavioral concept, the *autoclitic*. If "tall tree" was simply the combination of the two minimal repertoires, it would occur with equal probability as "tall tree" or "tree tall." The observation that in English we most often say "tall tree" requires an account of word order. Word order is one example of what Skinner (1957) described as an autoclitic. Autoclitics are defined as verbal operants that are under the control of, and modify, qualify, or describe other verbal behavior, thereby changing its effects on the listener. Word order can be considered an autoclitic frame into which combinations of abstract tacts may fit. For example, a person's first exposure to a tall tree may occasion the previously reinforced tacts "tree" and "tall." If the person has a history of reinforcement for behaving with respect to the autoclitic described by "adjectives precede nouns," then they are likely to respond "tall tree." The novel situation results in the responses "tree" and "tall" and the autoclitic frame, thus producing the novel response "tall tree" (Ellenwood & Chase, 1995). A similar account would also apply to a listener's behaving appropriately in response to novel verbal utterances. The systematic training of autoclitic frames is implicit in the research on miniature linguistic systems reported above. In the example given, the verb always preceded the noun. To train and test for this relation, however, would add another dimension to the matrix, word order, that would have to be systematically manipulated to produce discriminative responding to examples like "tall tree" versus "tree tall."

An enormous amount of novel behavior can be accounted for when these multiple sources of control are fully appreciated. In some sense, organisms are responding to stimulus features that are not novel but are only combined in novel configurations. It is extremely important to consider the power of novel stimulus combinations to produce environment–behavior relations that have not been observed before.

Equivalence Relations

Another concept, *stimulus equivalence* or *equivalence relations* (e.g., Sidman, 1986, 2000), provides an additional approach to understanding control by novel stimuli. Equivalence is a description of the observation that accurate responding to untrained relations among stimuli emerges after responding to a subset of the relations has been reinforced. For example, equivalence may be demonstrated in a matching-to-sample procedure with three or more stimuli in a class (A, B, and C). By establishing two conditional discriminations via differential reinforcement (AB and BC), seven (AA, BB, CC, BA, CB, AC, CA) may emerge without direct reinforcement. Equivalence is defined in terms of three types of emergent relations: reflexivity (e.g., AA), symmetry (e.g., BA), and transitivity (e.g., AC) (Sidman & Tailby, 1982). When reflexivity, symmetry, and transitivity are demonstrated, the stimuli involved are said to be members of an equivalence class in that their functions are interchangeable.

Such classes of interchangeable stimuli may be needed to account for the kind of novelty that occurs in some instances of verbal behavior. For example, once individuals behave with respect to the frame "adjectives precede nouns," the frame is effective when combined with a wide range of adjectives and nouns. Individuals, however, have to learn which words are adjectives or nouns, that is, to behave appropriately with respect to adjectives and nouns. One way of describing these parts of speech is as classes of equivalent stimuli. All adjectives are equivalent and all nouns are equivalent at the level of their position in a sentence. Thus, individuals may learn a few instances of adjectives before nouns (e.g., "red truck," "green ball"). They may also learn that the words in one class are interchangeable as adjectives (e.g., colors, shapes, heights, weights), and the words in another class are interchangeable as nouns (e.g., objects, people, animals). Finally, they *may* even learn to describe words as adjectives and nouns, although this step is not required. At this point, they only have to be told whether a word is an adjective or noun to use it properly in a sentence or to hear the word used in a sentence to classify it properly as an adjective or a noun. If after this training, individuals pass tests for reflexive, symmetric, and transitive relations among these words, then the classes are called equivalent (Ellenwood & Chase, 1995).

Sidman (1986, 2000) suggested that equivalence is a basic behavioral process made possible by contingencies of reinforcement. Others (e.g., Hayes, 1991; Horne & Lowe, 1996) suggest that equivalence is the result of a special verbal history. Still others have described equivalence as a type of relation among stimuli that is produced by the same contingencies of reinforcement responsible for responses to novel stimulus conditions described above (abstraction, the autoclitic, and minimal repertoires; cf. Hall & Chase, 1991). Regardless of whether equivalence is an extension of basic contingencies or some other processes, the phenomenon provides a powerful model for describing the emergence of novel behavior, particularly in verbal organisms.

The accounts of novel behavior discussed above depend largely on variations of the stimulus portion of a three-term (or larger) contingency. When considering novelty, however, our account would be incomplete if it did not describe how the response and consequence portions of any contingency also may vary. For this account it is helpful to understand selection and behavioral variability.

SELECTION, VARIABILITY, AND NOVELTY

The selectionist perspective taken by behavior analysts to account for behavior (including novel behavior) relies heavily on variability in behavior (cf. Donahoe & Palmer, 1994; Skinner, 1981; Staddon & Simmelhag, 1971). For example, when responses are made more likely as a function of their consequences, this result is described as reinforcement. After being reinforced, responses are said to have been selected from the behavior occurring in any given situation. Reinforcement as a selection process assumes, therefore, that there is variability in behavior from which responses can be selected. The variability in behavior that provides the substrate for selection may be induced by various methods (see Balsam et al., 1998, and Layng, 1991, for discussions) or explicitly reinforced (e.g., Goetz & Baer, 1973; Maltzman, 1960; Page & Neuringer, 1985). In the absence of such variability, selection could not occur. Conversely, selection may occur more quickly (under the appropriate conditions) when there is more variability in behavior. For example, LeFrancois, Chase, and Joyce (1988), Joyce and Chase (1990), and Weiner (1969) demonstrated that differences in the sensitivity of human behavior to changing schedules of reinforcement may be due to differences in the amount of variability observed in behavior prior to the change in schedules. Weiner and LeFrancois et al. showed that subjects with a history of responding on a variety of reinforcement schedules were more likely to show sensitivity to fixed-interval schedules than those exposed only to a single specific reinforcement schedule (variable ratio or variable interval). LeFrancois et al. and Joyce and Chase suggested that such increased sensitivity is due to the likelihood of contact with programmed contingencies permitted by variability in responding. In addition, Joyce and Chase found less sensitivity to changing reinforcement schedules after responding had stabilized (i.e., there was little variability in responding). Some instances of human behavioral insensitivity to manipulations of reinforcement schedules may be the result of instructions or specific behavioral histories that limit variability.

As noted in the introduction, variation is one of the fundamental characteristics of the operant. The operant is a *class* of responses that result in a characteristic consequence. The operant has been conceived as the result of reinforcement made dependent on some part of a distribution of responses, ordered according to the response dimension on which reinforcement depends (Catania, 1973). The notion of variability is inherent in describing behavior in terms of such distributions. According to this account, reinforcement acts by shifting response distributions via contingencies that select which responses along the relevant dimensions will produce reinforcement (Catania). Responses not meeting the requirements of the contingencies of reinforcement go unreinforced. If even slight shifts in the contingencies occur, the distributions may now include responses that previously had not occurred. The shaping procedures common in modern behavioral technologies explicitly take advantage of these shifting response distributions (e.g., Galbicka, 1994), but response distributions change when differential reinforcement occurs in any environment. Examples of such differentiating environments include those situations described as "problems" in problem solving (Skinner, 1953).

Skinner (1953) defined a *problem* as a situation in which a response that is highly likely cannot be emitted. For example, a person with a history of opening medicine bottles and having access to aspirin is presented with a problem when encountering a medicine bottle with a novel child-safety lock. Taking an aspirin is highly likely because of other conditions, like an ache in the shoulder, but cannot occur because the medicine bottle will not open. The previously learned behavior of unscrewing the lid is ineffective and is functionally placed on extinction. The problem is solved when a novel response opens the lid, and the aspirin is consumed. Emitting the highly likely response, however, is not problem solving; rather, problem solving involves behavior that manipulates the environment to allow the response to occur (Skinner, 1953, 1969). Thus, in the medicine bottle example, taking the aspirin is not solving the problem; problem solving includes the prying, twisting, searching, and so forth that occurs when simple unscrewing does not work. As Skinner (1953) stated, problem solving involves "emitting responses in great numbers because of previous success" (p. 248).

Variability is important when considering novel solutions to problems because in the absence of variability, a novel solution could not occur. A problem may occasion responses that have been reinforced previously in similar situations. If the behavior occasioned does not result in a solution, but the response persists, reinforcement will not occur. If the solution is important or necessary (i.e., has been established as a reinforcer), it is likely that other behaviors also occasioned by the situation will occur and some novel combination of these behaviors will produce a different outcome. If this outcome is the solution, in this case a reinforcer, a recombination of this sort would become a new operant.

Shaping may also occur during problem solving. Responses resulting from recombinations of previous behavior may produce stimuli correlated with the availability of the blocked response (e.g., the medicine bottle lid moves slightly). The production of these correlated stimuli may act as a reinforcer of responses that are approximations to the solution.

Resurgence

Describing problem solving in terms of behavioral variability and shaping, however, is probably not sufficient. The behavior that occurs during a problem is not just any behavior. Some distributions of behavior are more likely to occur than others. When faced with the medicine bottle that will not open, we do not sit on it or put it in a coffee grinder. Instead we twist, push, and pry the lid. We may engage in a variety of behaviors, but they are usually behaviors that have occurred previously and have been reinforced in similar situations. Understanding the generation of the novel behavior required for a solution, therefore, requires describing the conditions that give rise to recombinations of previous behavior (cf. Epstein, 1996).

Epstein (1983) noted that when one behavior is put on extinction, other behavior that was previously reinforced in the same context tends to reappear. The effect has been called *resurgence* and may help to explain novel combinations of previous behavior (Epstein, 1985). The contribution of resurgence to problem solving has been demonstrated by training various responses individually and then arranging a problem, the solution of which requires resurgence and recombination. As a demonstration of a behavioral account of Kohler's (1925) chimpanzee "insight," and as a replication of Birch's (1945) work, Epstein (1987) trained a pigeon to engage in several separate responses including pushing a box toward targets, climbing onto a box, and pecking a plastic banana in reach. Subsequently, the plastic banana was presented out of reach and only pecks to the banana were reinforced. Under the extinction conditions arranged by the new problem situation, the previously trained behaviors reappeared and combined to produce pushing the box under the banana followed by standing on the box and then pecking the banana. After the novel recombination was reinforced, the chain of originally separate responses became a functional unit and recurred when the problem situation was again presented. At this point, the recombination ceases to be a novel behavior and requires no special explanation.

The notion of resurgence, in conjunction with the observation that extinction produces an increase in variability (Antonitis, 1951), helps to account for novel responses to problem situations. The increased variability produced by the problem situation (extinction) is likely to include responses that were reinforced previously in similar or related environments (resurgence). Extinction and resurgence may make novel responses or recombinations more likely, and some subset of this novelty may produce the solution. These behavioral concepts can be combined with the stimulus control concepts described earlier (i.e., discrimination, generalization, conceptual behavior, tact extension, abstraction, minimal repertoires, and stimulus equivalence) to describe the conditions that produce the solution. In novel environments, stimuli that controlled responding in previous situations are present, but the responses they control are not reinforced. These extinction conditions produce an increase in variability, but not just any variability. The behaviors that occur are likely to be those that have come under the control of other stimuli in the environment. In some cases the stimuli that occasion a response can be accounted for by generalization, tact extension, or a minimal repertoire, and the response will be sufficient to produce the reinforcer. In other cases, however, the stimuli will produce a combination of responses (perhaps two minimal repertoires) that produces the reinforcer.

Problem Solving and Operant Variability Under Stimulus Control

Reinforcement also may be made dependent on variability in behavior. Some have suggested that variability is a dimension of behavior (like many others; e.g., force, duration, location) that is sensitive to the effects of reinforcement (e.g., Page & Neuringer, 1985; Pryor, Haag, & O'Reilly, 1969; Schoenfeld, Harris, & Farmer, 1966). In addition, Schoenfeld et al. noted that variability as a conditionable dimension of behavior must be considered with respect to some other dimension or dimensions. For example, reinforcement can be made dependent on variability of interresponse times (Schoenfeld et al.) or in sequences of responses (Page & Neuringer). Page and Neuringer reinforced sequences of eight key pecks by pigeons across two response keys only if the current sequence was different from some number of previous sequences. The variability in emitted sequences increased as the number of different intervening sequences required for reinforcement was increased. When the variability requirement was removed, but variability was allowed, behavior became highly stereotyped. These findings provide support for the notion that variability in behavior along some dimension is an additional reinforceable aspect of behavior (but see Machado, 1997). Well-controlled laboratory experiments like Page and Neuringer's provide evidence of variability as an operant by making reinforcement dependent on variability along one dimension and then measuring changes in variability along that dimension. The power of reinforcing variability in behavior to generate novel behavior also has been demonstrated in experiments that do not clearly specify a single dimension along which variability must occur. Pryor et al. reinforced variability in the behavior of porpoises and suggested that the outcome was "creative" behavior. Novel behavior was reinforced, and a large increase in the rate of novel behavior was reported. The novel behavior that was reinforced was not specified along any particular dimension, and the authors' descriptions of the resultant behavior suggest that it varied across a large number of dimensions (see also Eisenberger & Armeli, 1997; Goetz & Baer, 1973; Maltzman, 1960).

Page and Neuringer (1985) and Pryor et al. (1969) also found that variable responding can be brought under discriminative control. In one experiment, Page and Neuringer used a two-component multiple schedule with a variability requirement in one component and no variability requirement in the other. The resultant behavior was variable in the presence of the stimulus correlated with the variability requirement and stereotyped in the presence of the stimulus correlated with the absence of a variability requirement. Pryor et al. reported that the trainer's position on the edge of the water tank became discriminative for variable behavior. The observation that variability in responding along one or more dimensions can be brought under discriminative control may help to explain the rapid development of novelty that occurs in problem situations.

As noted above, the extinction introduced by problem situations is likely to generate increases in variability and make the resurgence of previously reinforced behavior more likely (see also Donahoe & Palmer, 1994, for a discussion). As a result, novel combinations that ultimately result in a solution to a problem are more likely. Although variability may be induced by the extinction inherent in problem situations, the finding that variability in operant behavior is also sensitive to its consequences and can be brought under stimulus control is likely important for understanding problem solving. The rapid onset of variable responding under the discriminative control of problem situations would make it more likely that a novel response could result in a solution to the problem. Skinner (1953) noted that discriminated variable responding may be involved in problem solving:

> An example of problem-solving in the sense of finding a solution appears in connection with trial-and-error learning when the organism "learns how to try." It emits responses in great numbers because of previous success and perhaps according to certain features of the problem. (p. 24)

Skinner's "learning to try" was characterized by the occurrence of great numbers of responses and may be the outcome of discriminated variable responding. A history of producing solutions that involve increased variability in behavior and novel recombinations make it likely that problem situations in general will occasion variable behavior. The resulting variability in behavior will be constrained by the stimuli present in any given problem situation and the responses occasioned by these stimuli or stimuli related by generalization, conceptual classes, extensions, abstractions, or equivalence (i.e., the current stimuli will determine which behaviors resurge). For example, in the medicine bottle example above, the behavior that is likely to vary would be determined by the person's history with respect to medicine bottles and related stimuli. Behavior that has previously been reinforced in the presence of a medicine bottle is likely to resurge (e.g., the way the bottle is held or the way the lid is twisted and manipulated in general). It is less likely that variability in how the person holds his or her mouth will occur; however, variability may occur in these other seemingly irrelevant behaviors as well. Such changes could be induced or result from a history of adventitious reinforcement (e.g., in a similar situation the person stuck his or her tongue out just before the bottle opened). In fact, behavior that was previously induced or adventitiously reinforced might occur in the current problem situation and, in combination with other behavior, lead to reinforcement.

Verbal Problem Solving

The importance of the notion of variability as an operant also applies to problem solving in verbal behavior. Problem situations involving verbal behavior occur in many forms, and they seem as likely to give rise to discriminated operant variability as nonverbal problem situations. Examples of verbal problem situations may include silence in an ongoing verbal interaction, the contingencies applied by verbal communities to not repeat oneself, the demands of the verbal community to generate novel contributions to art, science, and writing, and situations discriminative for verbal humor. The dimensions along which verbal behavior may become variable in these problem situations are more difficult to specify than in their nonverbal counterparts. For example, the behavior that arises from a break in conversation is likely to vary with respect to the topic of the conversation. The familiar "flow" of conversation or "train" of thought seem to characterize this sort of variability.

The novelty arising from variability in verbal behavior can be understood like most of the novel behavior described above. The current situation does not reinforce a particular response; it provides novel combinations of stimuli (verbal and nonverbal) that occasion previously reinforced behavior, and leads to an increase in variability that may ultimately result in a novel combination of previous behavior. The probability of reinforcement for any novel verbal recombination that results will depend on the speaker's verbal community.

VARIATION IN CONSEQUENCES

Finally, novel behavior also likely arises from variations in the consequences of behavior. As noted above, an operant class is defined by the effects of a characteristic consequence on the responses in the class. Novel behavior may be generated, however, when a class of responses maintained by one consequence comes under the control of a different consequence. For example, a person's bicycle riding may be maintained by the reinforcement associated with getting to work each day. By riding each day, however, other reinforcers may be contacted (i.e., shapely legs or increased overall energy). The first instance of bike riding maintained only by these other reinforcers is appropriately considered a novel instance of behavior. A casual description of this situation, for example, "I started riding my bicycle as a way to get to work, but now I also do it for exercise" likely reflects this novel operant class.

Stokes and Baer (1977) recognized the contribution of variation in consequences of behavior in their discussion of ways to program the generalization of behavior from therapeutic situations to the natural environment. For example, we may use contrived reinforcers to initially bring behavior under control, but the continued success of most treatments requires transfer of control to naturally occurring reinforcers that do not include the therapist, teacher, or scientist who provided the contrived reinforcers. For example, we may initially reinforce an autistic child's eye contact with candy, but eventually this behavior must come under control of natural social reinforcers. If the behavior does come under the control of these natural reinforcers, then a novel operant class has been generated.

The effects of variations in consequences have received little attention in basic research. However, varying the consequences of behavior has been used to produce oral consumption of drugs of abuse by nonhumans (see Meisch & Carroll, 1987, for review). In these procedures, responding initially is reinforced by the delivery of food or a sweet sucrose solution, and then a drug is substituted for the food or gradually faded into the solution as the sucrose is faded out (e.g., Samson, 1986). Thus, a novel behavior (i.e., drug taking) is generated. These procedures have been critical for the development of animal models of drug taking because they overcome the initially aversive taste of the drugs and bring the animal's behavior into contact with the reinforcing effects of the drugs. Social and other reinforcers also are likely to maintain human drug taking before such behavior comes under the control of the effects of the drug (cf. S. M. Alessi, Roll, Reilly, & Johanson, 2002).

A considerable amount of novel behavior may arise in a similar fashion. Behavior previously generated or maintained in the context of one contingency provides the first instance of a novel class that will develop as a result of contact with a novel reinforcer. These effects also likely interact with the sources of novelty described above.

CONCLUSION

Many concepts central to behavior analysis, including selection, the operant, reinforcement, and stimulus control, depend on variability. Such variability has its roots in all terms of the three-term (or larger) contingency that defines a unit of behavior and lays the foundation for novel behavior. Variability also may function as a discriminated operant. This observation provides a means to account for novelty in terms of increases in variability that accompany the presentation of problems. The variability occasioned by problem situations likely interacts with other sources of variability. Interactions with discrimination, generalization, conceptual behavior, tact extension, abstraction, minimal repertoires, the autoclitic, and equivalence provide an extensive array of tools for dealing with novel instances of behavior. Once an instance of behavior occurs, perhaps generated through variation in the stimulus or response portions of the contingency, the behavior may come into contact with a novel reinforcer and form a novel operant class. These behavior-analytic concepts provide an effective means for understanding novel behavior and can be said to emphasize the importance of novelty rather than ignore it.

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